Report No. 79-3 July 1979

AN EVALUATION OF WHITE PINE BLISTER RUST IN THE SIERRA NEVADA

James W. Byler
Plant Pathologist
USDA Forest Service, Region 5

John R. Parmeter, Jr.
Professor of Plant Pathology
University of California, Berkeley

Forest Insect and Disease Management
USDA Forest Service, Region 5
630 Sansome Street
San Francisco, California 94111

The evaluation, done primarily by James W. Byler, is based on observations and results of surveys made in the northern Sierra Nevada during the past 10 years. The surveys were made under the direction of John R. Parmeter, Jr., and Neil J. MacGregor.

CONTENTS

ABSTRACT

In the late 1960's the Forest Service began a review of the blister rust situation in California. Surveys were made in the northern Siera Nevada to determine the incidence of rust infection and damage to sugar pine. More than 50% of the trees were infected in several incidence survey units, and most infected sugar pines in those areas were lethally infected. However, the mean level of infection was below 20% even though the incidence survey was made in and around the oldest known infection centers in the Sierra Nevada, centers that had been active for two to three decades. Furthermore, the damage survey indicated that many infected, pole-sized and larger trees will reach merchantable size. The following management suggestions for Sierra Nevada forests are based on the survey results:

1. Don't automatically discriminate against uninfected sugar pines because of the blister rust threat. Some will be rust-resistant. Many others will escape infection, especially if they are growing in locations where the climate is not ideal for pine infection. And the probability of death from rust infection decreases as the tree increases in size.

2. During precommercial thinning, uninfected sugar pine may be selected as crop trees. The risk of losing a substantial proportion of the trees before they reach merchantable size is low, especially if the trees are 3" or 4" dbh at the time of thinning. Infected trees should be cut, although lightly infected trees may be pruned free of branch infections if they are 4" or more from the stem.

3. Uninfected sugar pines left during commercial thinning are not seriously threatened by the rust. Infected trees need to be removed only if large branches are infected and the cankers are at or near the stem.

4. Plant sugar pine with caution. Plant non-resistant pine only when the rust is absent, and even in areas of no apparent rust, plant a mixture of at least two tree species. Small trees are very vulnerable to the rust and plantations can be severely damaged in one severe rust year.

INTRODUCTION

White pine blister rust, a native of northern Asia, was introduced into the United States from Europe. The initial infection center in the West (near Vancouver, British Columbia) has been traced to a shipment of white pine seedlings in 1910.

The rust spread south through Washington and Oregon, entering California by 1920. By 1938, infection centers had become established on sugar pine in the northern and central parts of the Sierra Nevada. White pine blister rust is an obligate parasite. It is able to survive and reproduce only on a living host. Furthermore, the rust fungus requires a second host to complete its life cycle. Aeciospores, produced on pine stems in the spring, can infect only the alternate host, species of *Ribes*. Urediospores, produced on ribes leaves in the summer, can infect only ribes. Teliospores, produced from ribes leaves in the fall, produce basidiospores that reinfect pines.

Experimental ribes eradication began in California in the mid 1920's. As in other white pine regions, the control was a preventative effort based on eradicating gooseberry and currant plants, the alternative hosts of the fungus. By the early 1930's, eradication was underway within selected sugar pine protection units in the Sierra Nevada, and by the early 1940's, protection units totaling more than two million acres extended from the Oregon border to the southern Sierra Nevada. At the height of the program, more than 10 million gooseberry and currant plants were destroyed each year.

As information on the behavior of blister rust under California conditions accumulated, it became evident that the disease was causing substantially less damage in California than farther north(2). This is mainly because the conditions that are required for long-distance spread, spread from ribes to ribes and ribes to pine, occur less frequently in California.

In the late 1960's the Forest Service began a review of the blister rust situation in California (5). An incidence survey was made at selected locations in the northern Sierra Nevada in 1969 and 1970 to determine what proportion of the sugar pines was infected within established disease centers. A damage survey was made in 1971 and 1972, to determine whether both large and small trees were killed by the rust. As a result of these surveys and information from other sources, the program shifted from ribes eradication to cultural and genetic control. The major findings of the surveys are presented in this paper, as well as an evaluation of the survey results and a discussion of sugar pine management under the impact of the continued presence of the fungus.

INCIDENCE SURVEY

The progress of the rust in California was followed by scouting surveys made largely along streams to locate new infection centers. By the 1960's it was evident that the rust was well distributed throughout the northern Sierra Nevada.

It was also apparent that not all sugar pines were infected, even in locations where the rust infection was heavy. During 1969 and 1970, an incidence survey was made at northern Sierra Nevada locations known to be infected to answer one question: what proportion of the sugar pines had became infected at each center during some thirty years of rust build-up? Since the survey areas were not randomly selected, but were chosen to include the oldest known infection centers, the average of all areas cannot be considered statistically representative of the northern Sierra Nevada.

METHODS

Field data were collected within 114 preselected areas in the northern Sierra Nevada on the Lassen, Plumas, Tahoe and Eldorado National Forests. Areas were chosen to include the oldest known infection centers in this part of the State, many of which dated to 1944 or earlier. Survey lines were run 10-chain aparts, within each 600 acre area. Point samples were taken at 5-chain intervals along each survey line. The two sugar pines nearest each sample point were examined for blister rust. Trees of all sizes were selected, provided they had green branches within 18 feet of the ground. Each point was classified as upland or stream type; a stream plot was one in which surface water (flowing stream, spring, wet meadow, lake, etc.) occurred within one chain of the point. Typically, about 500 trees were examined for rust in each area surveyed.

RESULTS AND DISCUSSION

Figure 1 shows the percentage of sugar pines found to be infected in each of the 600 acre survey areas, the mean infection percentage for all areas in each Forest, and the means for the upland and stream sites on each Forest. Within an area there was often considerable variation in the level of infection, and the levels approached 100% in localized portions of a 600 acre area. But, it is readily apparent that not all

sugar pines have been killed by the rust, even in the oldest known infection centers after 20-25 years of exposure, and the percentage of sugar pines infected was below 20% for most areas. The survey was made in 1969 and 1970, and infection that occurred later than about 1966 would not have been noticed. Additional infection has occurred within the areas surveyed as a result of "wave years" of infection since then. Infection seemed particularly heavy in about 1972 and again about 1976.[1/] A complete assessment of the impact of the most recent infection has yet to be made. Still, the general findings of the survey are believed to be valid: rust incidence is spotty, and a large portion of the sugar pine in the northern Sierra Nevada are uninfected, even within the oldest known infection centers.

Survey results support the common observation that the level of infection in stream type is generally higher than in upland type. However, some upland areas do have high levels of rust. And observations suggest that the influence of surface water extends considerably beyond the one chain distance that was arbitrarily selected for the survey.

DAMAGE SURVEY

Rust infection frequently, but not always leads to tree death. Infection takes place through the needles, and from there the fungus grows down the needle into the branch. The branch is encircled and eventually the infected tissue dies, resulting in girdling and death of the branch.

When the bole of a young tree is infected either through direct infection of stem needles or following growth of the fungus down a branch, the bole is encircled by the fungus. The tree, or that portion of the tree above the canker, dies following encirclement.

Infections are less apt to kill large trees. Most infections tend to be in the lower 10-15' of the larger trees. Most of those infections occur far out on branches and tend to become inactive before reaching the bole. In one study, cankers on sugar pine whose closest margins were more than about 18" from the stem apparently died out before reaching the stem (1).

[1/] See W.L. Freeman's letter of July 19, 1978, to the Lassen N.F., and his letter of October 24, 1978, to the Plumas and Lassen National Forests regarding white pine blister rust evaluations made in selected plantations on those Forests.

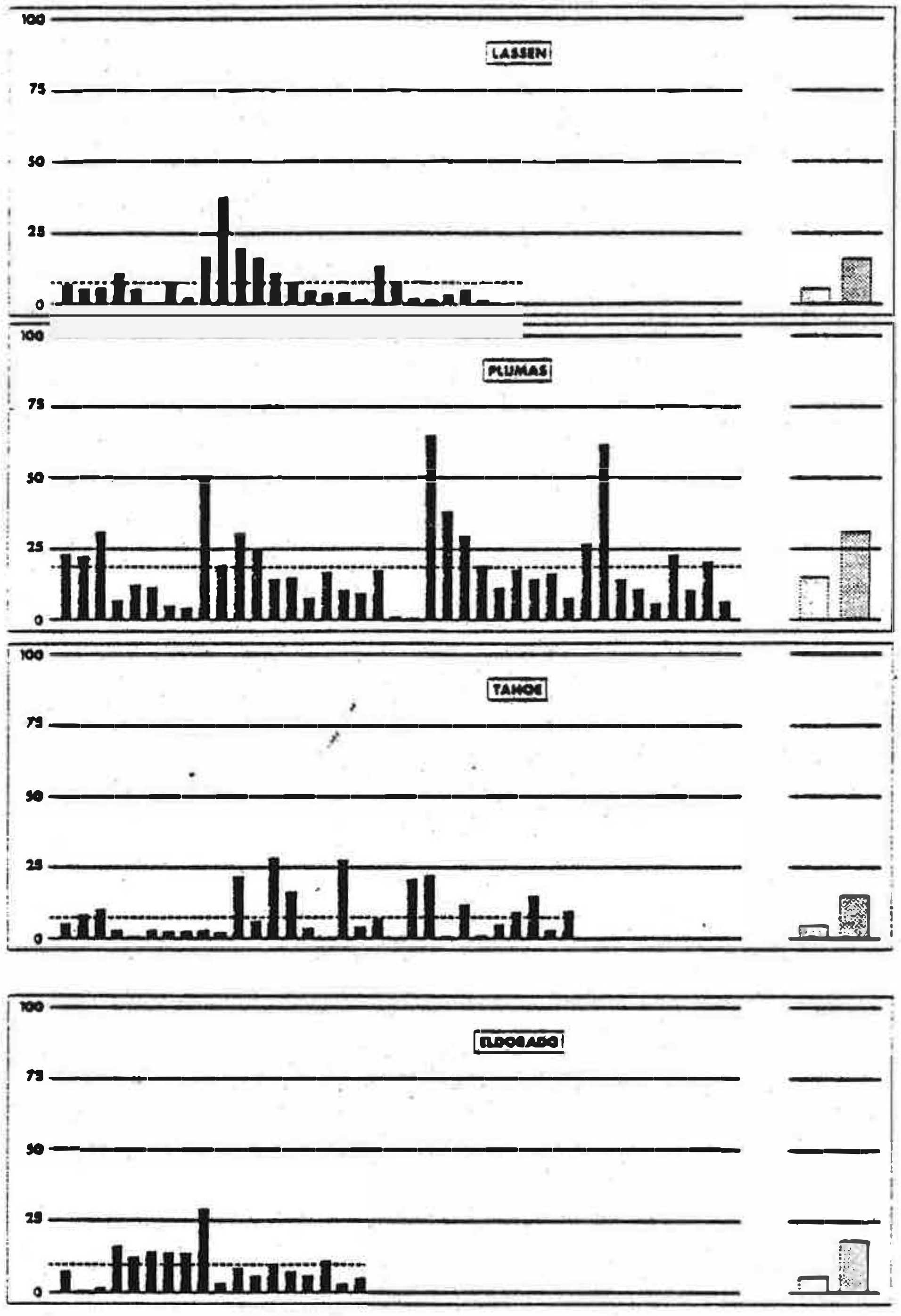

FIGURE 1: The percentage of trees infected in each incidence survey area (solid bars), the National Forest average (the dotted line) and the average infection for upland and stream locations (diagonal and cross hatched bars).

Furthermore, not all lethal cankers cause immediate tree death. The fungus grows down sugar pine branches at the rate of about 1-2 inches per year (1), and it may take several to many years for a canker to reach the bole. The rate at which the blister rust fungus encircles and kills sugar pines is not known. However, based on data collected during this damage survey, it appears that small boles are encircled and killed in a few years while large stems may live for decades. The purpose of the damage survey made in 1971 and 1972, was to determine the height and proximity to the bole of cankers on sugar pine trees of various sizes. From these data we can define the sizes that would be killed by the rust and those that would not.

METHODS

Fourteen locations were selected for the survey, seven each on the Lassen and Plumas National Forests. These two Forests were selected because they contained the oldest known cankers in the Sierra Nevada, and the highest infection levels. Silvicultural control options that are suitable on these Forests could be used where there was less rust.

Areas were surveyed that 1) contained sugar pine as a major portion (20% or more of the trees in the stand) of the mixed conifer type, and 2) had sugar pines one to 16 inches dbh, and 3) contained moderate to high levels of blister rust. As with the incidence survey, the rust had been present in the areas since at least the 1950's, some since the mid 1940's, and most infection was the result of several unusually heavy infection years beginning in the early 1960's (5). About half of the plots were established within areas that were a part of the earlier incidence survey.

A strip cruise was made through each area, either along the stream bottom (in the case of stream plots), or along a side hill or ridge (in the case of the upland plots). All 1-8" dbh sugar pines within ½ chain of the strip and all 8-16" dbh sugar pines within 2 chains of the strip were tallied by diameter (dbh), crown class, and presence or absence of infection.

A total of 40 infected trees were cut and examined in each area, 10 trees in each of four dbh classes: 1.0-2.0" (1-2"), 2.1-4.0 (2-4"), 4.1-8.0 (4-8"), and 8.1-16.0" (8-16"). Tree height, number of cankers, canker height, canker age, distance of the cankers to the stem, and other measurements were recorded for each cut tree. Means and confidence intervals were calculated for tree diameter classes.

The following four classes of rust infection were designated for trees based on the position of the cankers in the tree.

Class 1. Infected trees with no cankers within 24 of the stem. Trees will live indefinitely, since cankers whose closest margin is 24" or more are unlikely to reach the stem.

Class 2. Infected trees whose closest infection is less than 24" but no less than four inches from the stem. None of the cankers are above one-half live crown height in the tree. The trees are lethally infected. However, pruning the trees to half the height of the live crown would remove all lethal cankers.

Class 3. Infected trees whose closest infection is less than 24" but not less than 4 inches from the stem. Unlike the above class, lethal cankers occur above half crown height and would not be removed by routine pruning to half crown height.

Class 4. Trees with cankers within 4" of the main stem. Such trees are lethally infected and would not be saved by pruning. The rust fungus sometimes extends beyond the visible margin of infection as much as 3-4 inches.

RESULTS AND DISCUSSION

Table 1 shows the percentage of sugar pines infected at each of the survey locations. Although the locations were not randomly selected, they show the same trends as the incidence survey: the percentage of trees infected is greater in streams than upland sites and the level of infection is greater in the Plumas than in the Lassen National Forest locations. The percentage of trees infected in each Forest was about 3 times higher than the percentage obtained for the incidence survey. This most likely reflects a difference in the way the survey areas were delineated. The areas surveyed in the incidence survey were large and covered a drainage from ridge to ridge, and contained sub-units of both low and high rust incidence. The strip plots for the damage survey covered much less area, and were run only through the portion of a drainage that was infested.

Table 1. Percentage of sugar pines infected with blister rust at 14 damage survey locations.

Location		Percent Infection
LASSEN N.F.		
Middle Hollow	(Upland)	18
Middle Hollow	(Stream)	38
Willow Creek	(Upland)	18
Willow Creek	(Stream)	47
Upper Yellow Creek	(Stream)	52
Last Chance	(Upland)	30
Kimberly	(Upland)	13
	Upland $\bar{X}$	20
	Stream $\bar{X}$	46
	Forest $\bar{X}$	31
PLUMAS N.F.		
Mooreville Ridge	(Upland)	48
Miller Fork	(Stream)	89
Miller Form	(Upland)	84
Dark Ravine	(Upland)	61
Grizzly Ridge	(Stream)	87
Grizzly Ridge	(Upland)	36
Taylor Creek	(Stream)	64
	Upland $\bar{X}$	57
	Stream $\bar{X}$	80
	Forest $\bar{X}$	67

Lethal Cankers. For purposes of comparison, the plots were grouped into those moderately infected (13-64% of the trees) and those very heavily infected (84-89%).

In the three plots where rust was very heavy, most infected trees were lethally infected (Class 2, 3 or 4 infection: one or more cankers within 24" of the stem). Fewer than 5% of the trees of all sizes fell into Class 1 (no infections within 24" of the stem). At such locations where the rust infection is extremely heavy, there is little chance of growing seedlings or saplings to merchantable size once infected.

Many trees in the plots where infection levels were moderate were not lethally infected, and would not die of present rust infection. The proportion of trees that were lethally infected was much greater for the small tree diameter classes (Figure 2). Nearly all (99%) of the 1-2" dbh infected trees were lethally infected. However, nearly half (44%) of the 8-16" dbh trees were not lethally infected and would not be killed by the rust.

Figure 3 indicates that pruning the lower one-half of the crown would eliminate all lethal cankers on a sizeable proportion of the trees. Selective pruning of canker branches above that height would free additional trees of cankers. About 40% of the infected trees in the 2-4" and 4-8" classes would be pruned free of lethal cankers by pruning to half tree height. Five percent of the trees in the 1-8" dbh classes that had infection 6-24" from the stem had lethal cankers above ½ crown height and would require higher pruning.

Figure 4 summarizes the infection for the 11 moderately infected plots. It shows the proportion of trees in each size class that was uninfected, and the proportion that was infected but had no cankers within 24" of the stem.

Even in these stands where the rust had been present for more than a decade, stands which had been subject to several heavy rust spread years, a high proportion of the trees in most size classes are uninfected or infected but free of lethal cankers. If necessary, some individual infected trees could be pruned free of lethal cankers at the time of precommercial thinning.

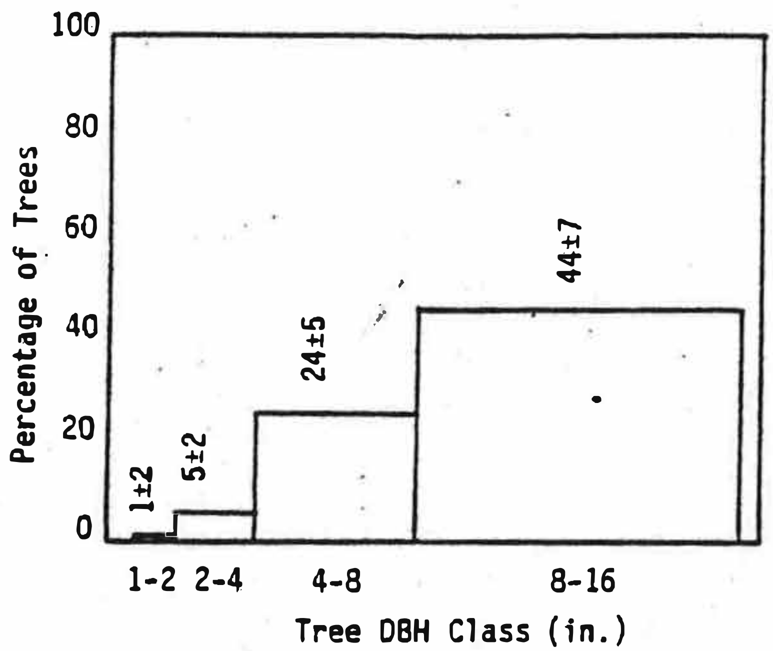

FIGURE 2. Proportion of the infected trees in the moderately infected plots that are not lethally infected (Class 1 trees).[1]

[1]No infections within 24" of the stem.

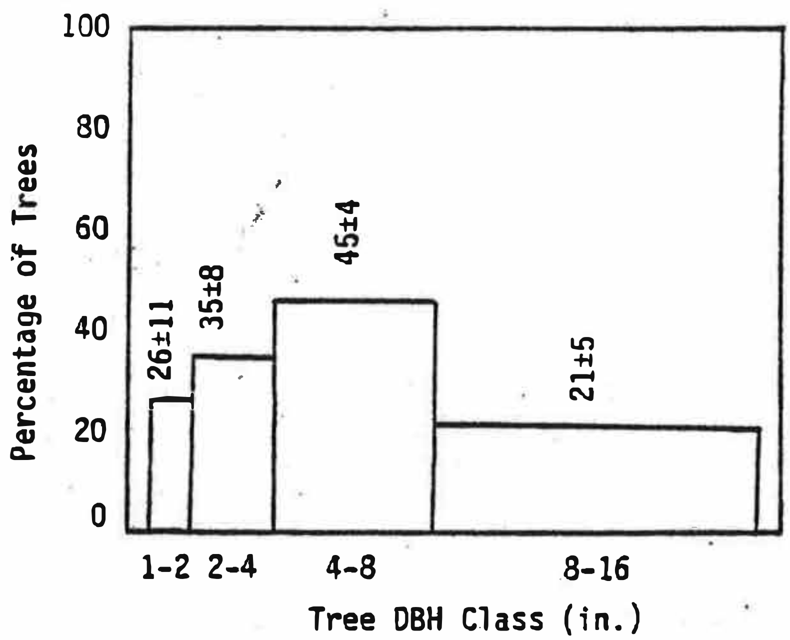

FIGURE 3. Percentage of infected trees in the moderately infected plots that would be pruned free of lethal cankers if the lower one-half of the live crown were pruned (Class 2 trees).

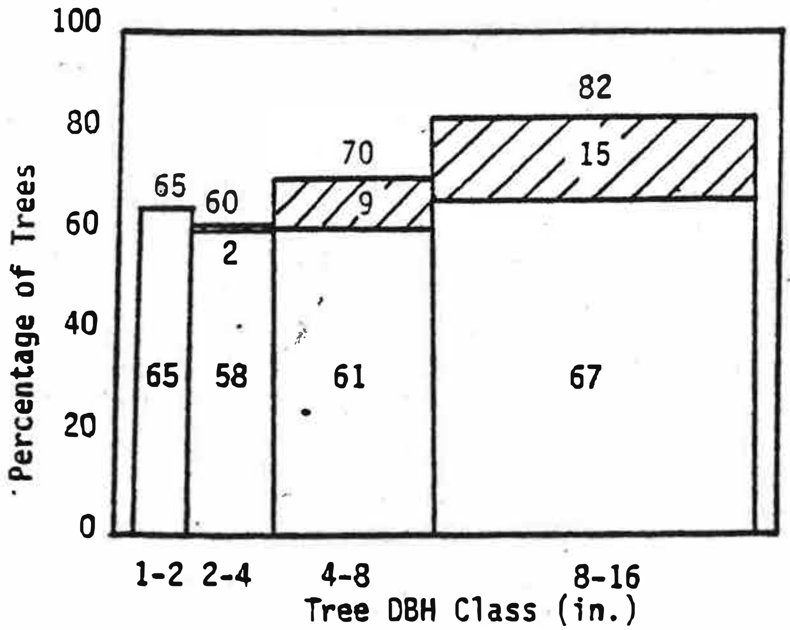

FIGURE 4. Proportion of all trees in the moderately infected plots that were uninfected (plain bars) or infected but free of lethal cankers (diagonally striped bars).

Life Expectancy. Not all lethally infected trees will die immediately. Time is required for the fungus to grow down the branch and girdle and kill the stem. Life expectancies were calculated for individual trees, based on the following assumptions:

1) Trees would grow at the average rate of 1" in diameter every 5 years.

2) Cankers would progress down the branches at a rate of 1" per year for branches less than 0.5" in diameter and 2" per year for larger branches.

3) Three-to-four inch dbh stems would be encircled, girdled and killed in 10 years, 5-6" stems in 15 years, and stems 7" or larger in 20 years.[1/]

Table 2 indicates that trees 7" dbh or larger, when infected, are to be expected to live until they reach 12" dbh. The data also suggest that if a stand were precommercially thinned at a size of 5-6" dbh, few infected trees would die from new infections before reaching minimum merchantable size of 8" dbh. About half would live to at least 12" dbh.

Thinning in smaller trees would be more risky. Even so, most (73%) trees infected at 3-4" dbh would likely live to the minimum 8" size.

MANAGEMENT OPTIONS

The incidence survey showed that a substantial proportion of the young sugar pines were uninfected in the oldest known blister rust infection centers in the northern Sierra Nevada. Additionally, observations made throughout the Sierra Nevada indicate the rust is absent in many stands with sugar pine.

The damage survey showed that death is not inevitable following blister rust infection. Although small pines (less than about 3-4" dbh) are nearly always killed, larger ones may have no lethal cankers (defined as those that originate within 24" of the stem), or if they do they may reach merchantable size before death and be harvested.

[1/] Unpublished data collected during the damage survey suggest these estimated rates of girdling are reasonable.

Table 2. Life expectancy of infected sugar pine.

DBH Class at the time of infection	Percentage of infected trees that will reach:	
	8" dbh	12" dbh
1-2	15 ± 11	7 ± 4
3-4	73 ± 10	22 ± 4
5-6	95 ± 3	59 ± 12
7-15	100	100

Taken together, these findings indicate that we can manage existing sugar pine stocking in spite of blister rust on many sites in the Sierra Nevada. Observations suggest that the survey results are likely applicable to stands throughout the Sierra Nevada, at least as far south as the Sierra N.F. Conditions may be more favorable for rust infection in the vicinity of Sequoia N.F., than others farther north, possibly due to the more frequent late summer rains.

Precommercial Thinning. Uninfected trees are present in stands where the rust has been present for two decades or more. Such trees may have escaped the rust because of limiting environmental conditions. Some likely have genetic resistance (4). Either way, they should be considered candidate leave trees during precommercial thinning. The results indicate that the risk of losing a substantial number of leave trees to the rust following a precommercial thinning is low if sugar pines are uninfected at the time of thinning. Even if heavy rust infection occurred immediately following the thinning, most infected trees that were more than 3 or 4" dbh would live to a size of 8" dbh and many would reach 12".

It may be advantageous to postpone thinning in rust infected, precommercial sized natural stands or plantations if the stands are fairly open and natural pruning of the lower branches has not yet occurred. Closer spacing that leads to rapid natural pruning will reduce the likelihood of infection since most cankers occur low in the trees.

The rust has a very high reproductive rate, and the percentage of trees infected can increase greatly in one year. Unusually heavy infection in one year can result in lethal infection of a sizable proportion of the leave trees in local areas. As insurance against such occasional loss it is advisable to maintain a mixture of tree species following thinning.

It should be emphasized that the success of precommercial thinning in rust infected stands may be dependent upon the selection of rust-free leave trees. A failure to recognize rust infection in the stand, and to examine leave trees for rust, can lead to death of the infected leave trees and understocking of the stand.

Commercial Thinning. Uninfected trees that are left after commercial thinnings (assuming even-aged management) are not seriously threatened by the rust. And infected trees can theoretically be left during commercial thinnings. The data suggest that 10-20 years are required to girdle and kill stems of 3-7" in diameter at the point of branch entry. Thus, only trees with infections on or near stems of smaller diameters, and those partially girdled by the rust already risk being killed before the next stand entry, if the entry is within 10 years.

From a practical standpoint, however, a sugar pine with dead branches in the upper crown should probably be removed from the stand when thinning. Dead branches above the height where natural pruning occurs is a reliable indicator of rust infection on sugar pine in stands when the rust is present. Cankers that are not visible from the ground may reach the stem and kill the tree before the next cutting.

Regeneration. From a silvicultural standpoint it is often desirable to maintain sugar pine in the mixed conifer stands in the Sierra Nevada. Summaries of the survey results presented above indicate that the rust will not preclude this on many upland sites. Natural regeneration with sugar pine appears to have acceptable risks, if very high-hazard sites are avoided, and if sugar pine is but one of several tree species.

The planting of sugar pine is more risky. Even with careful site selection some plantations will be damaged, a few severely, since sugar pines are vulnerable to the rust for 20 years or more following planting.[2/] Plantation establishment often enhances ribes production, and local infection can be heavy enough to virtually eliminate young sugar pine regeneration. For this reason sugar pine is best planted in upland areas where no rust is present, and then only in mixtures with other tree species.

Site Hazard Rating. Rust infection levels vary greatly from stand to stand, from no rust to greater than 90% of the sugar pines infected. Unfortunately, no definitive method for determining rust hazard is known. Hazard depends upon the abundance and species of ribes, the amount and duration of moisture during the summer, the amount and timing of fall rains, and geographical and topographical features (2). Most, but not all, of the very high hazard sites are in stream bottoms, or near standing water such as lakes. The rust is at times severe on upland sites, especially on the Plumas N.F., where the highest levels of rust in the Sierra Nevada are known.

At present, the most useful indicator of rust hazard for a stand appears to be the level of rust that is currently present. If a substantial proportion of the sugar pines in the present stand are infected (perhaps 25% of more), natural regeneration of the site with non-resistant sugar pines will likely fail. Stands with rust should probably be planted only with rust-resistant sugar pine, or other suitable tree species. Documentation of high rust hazard using the Region's stand record card will prevent costly future mistakes.

[1/] See W.L. Freeman's letter of July 19, 1978 to the Plumas N.F., regarding blister rust in the Soapstone Plantation.

Pruning Blister Rust Infections. Damage survey results suggest that pruning is a biologically feasible method for controlling the rust in areas where the level of infection is not excessive. A substantial proportion of the infected trees between 2 and 8 inches in diameter would have been pruned free of cankers if they had been pruned to half tree height, or to 18' for trees taller than 36'. Alternative methods of pruning (pruning only the lower third of the crown, but cutting infected branches from the lower whorls left) would likely accomplish the same rust control.

However, the practical use of pruning as a rust control measure may be limited because of high costs. Pruning is expensive and in most stands where the infection level is moderate and pruning would be effective, there will be enough uninfected sugar pines or trees of other species present to select from for leave trees.

The method may have limited application in stands that are 4-6" or more in diameter, that are heavily infected, and that have inadequate numbers of uninfected desirable sugar pines or leave trees of other species. The pruning of selected, lightly-infected sugar pines during precommercial thinning may allow the stand to reach merchantable size, and may be less expensive than regenerating the stand.

Northwestern California. The rust has been generally more damaging in the Coast Ranges in northern California than in the Sierra Nevada. The rust is sufficiently heavy on the Klamath, Six Rivers and Shasta-Trinity National Forests to make the planting of non-resistant sugar pine questionable. However, even there, infection varies greatly. Not all stands with sugar pine are infested, and not all sugar pines in infested stands are infected. Uninfected sugar pines need not be cut when treating these stands.

Integrated Pest Management. An integrated pest management strategy has been developing in California, as it has been elsewhere in the West (6). The strategy for white pine blister rust is based on genetic and cultural control. The genetic approach relies on dominant gene resistance for the immediate future, and promises the eventual incorporation of other, longer-lasting resistance types for the future (3). Cultural control is feasible where rust hazard is low. It can also be used to supplement resistance. Key features of the cultural control strategy are the recognition and removal of lethally infected sugar pines during precommercial thinnings, and the selection and designation of low and high hazard sites. An approximation of site hazard based on topography, latitude, and presence or absence of the rust is possible now. More precise evaluation criteria would allow the culture of sugar pine with greater confidence, and the avoidance of the occasional high losses of young pines that can occur, especially in plantations.

LITERATURE CITED

1. Harvey, G.M. 1967. Growth rate and survival probability of blister rust cankers on sugar pine branches. U.S.D.A. Forest Service. Research Note, PNW-54. 6p.

2. Kimmey, J.W. and W.W. Wagener. 1961. Spread of western pine blister rust from ribes to sugar pine in California and Oregon. U.S.D.A. Forest Service. Research Bul. No. 1251. 71p.

3. Kinlock, Bohen. 1976. Breeding for white pine blister rust resistance in sugar pine: An operational plan for Region Five. P. 98-123. In Tree Improvement Master Plan, J.H. Kitzmiller. U.S.D.A. Forest Service, Region Five, San Francisco.

4. Kinloch, B.B., Jr., G.L. Parks and C.W. Fowler. 1970. White pine blister rust: simply inherited resistance on sugar pine. Science 167:193-195.

5. MacGregor, N.J. 1969. BRC program review. Disease Report 1, 5270, U.S.D.A. Forest Service, Region Five, San Francisco, 20p.

6. McDonald, G.I. 1979. Resistance of western pine to blister rust: a foundation for integrated control. U.S.D.A. Forest Service Note, INT-252, 5p.

ACKNOWLEDGEMENTS

The authors appreciate the assistance of Glen R. Davies, Neil J. MacGregor, Douglas R. Miller, Detlev R. Vogler and Wayne T. Williams.